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~~SECOND~~ QUARTERLY REPORT

HEAT PIPE THERMIONIC CONVERTER DEVELOPMENT

~~Contract No.~~ 951465

1 October 1966 to 10 January 1967

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

Prepared for

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1. Introduction

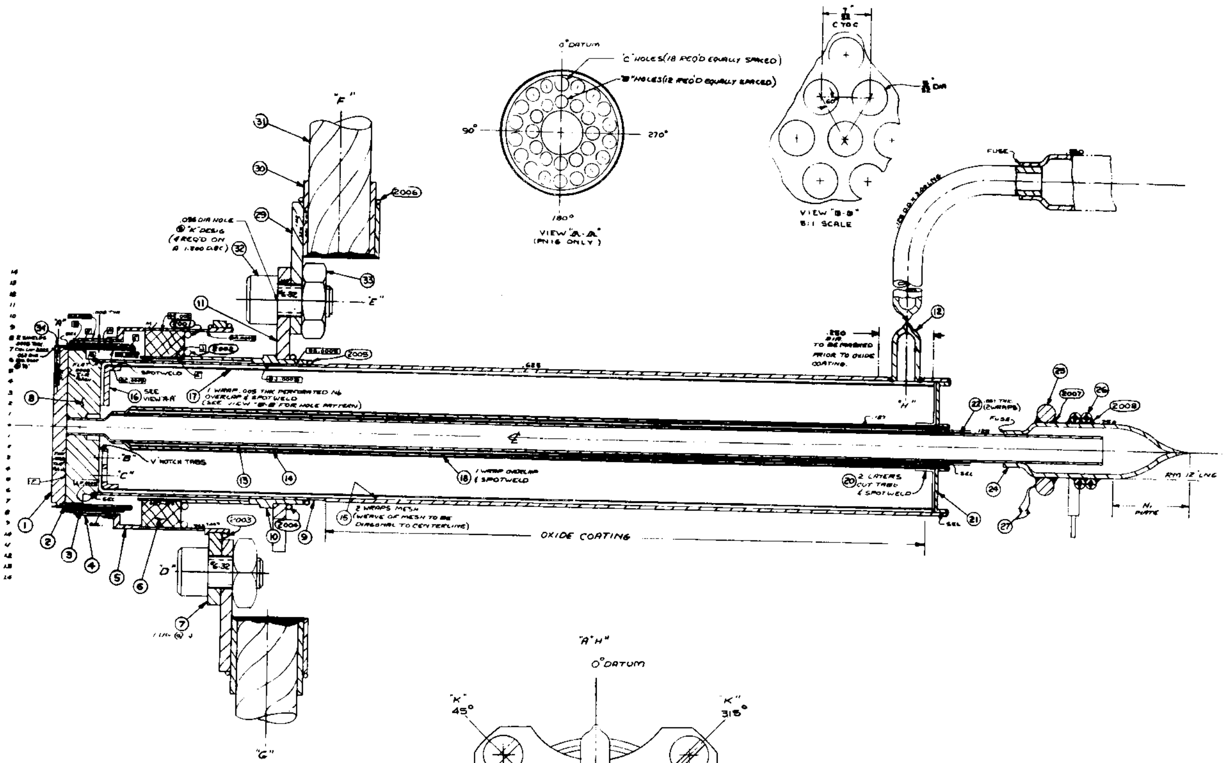
This document constitutes the Second Quarterly Report of the work being performed under Thermo Electron's Contract No. 951465 with the Jet Propulsion Laboratory.

The objective of this program is to develop a converter of the design used in Contract No. 951263, and which incorporates a heat pipe concept to transfer heat between the collector and the radiator. The work involves the design, fabrication and test of two heat pipe models designated T/E-1 and T/E-2, and two heat pipe thermionic converters designated EM-1 and HP-1. The four devices are to be fabricated and tested in sequence to allow a thorough evaluation of each design before proceeding with the next iteration. Since the development of a suitable heat pipe structure is the most important aspect of the work under this contract, the first two devices include only the heat pipe, and it is only in the last two that an attempt is made to fabricate a complete converter structure incorporating a heat pipe collector radiator.

This report covers progress for the period 1 October 1966 to 10 January 1967.

2. Fabrication of T/E-1-A

The fabrication of T/E-1-A was started with the weld of the cesium reservoir tube assembly, parts Nos. 13 and 14, to the collector, part No. 8 (see Figure 1). Because it was found extremely difficult to reduce the diameter of the tantalum cesium tube at the end that is inserted



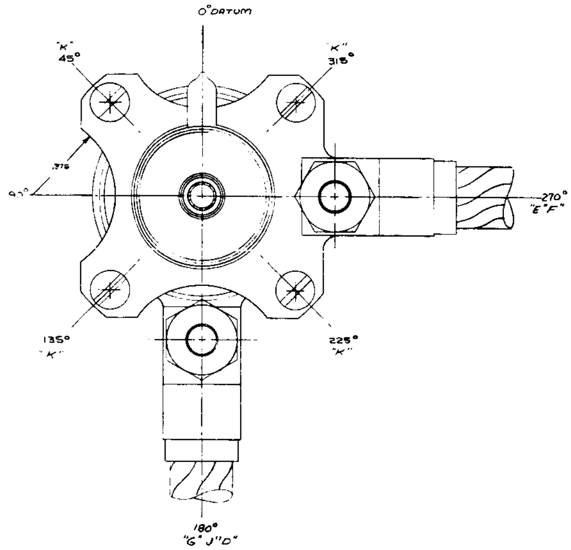


Figure 1

in the collector, the design was changed to omit the diameter reduction of the tube and to enlarge the corresponding collector hole. The weld of the tube to the collector required a relatively large amount of heat, and, although it could be successfully made, it resulted in a large amount of erratic melting on the collector face near the center hole. Also, the collector face was considerably oxidized, and the oxidation was suspected at that time to be due to outgassing of the electrode support in the welding chamber.

Next, the radiator tube subassembly, parts Nos. 9 and 12, as coated by New England Hard Facing with Norton's Rockide C coating, was welded to the edge of the collector. For this operation, the three parts of the seal assembly, Nos. 6, 10 and 11, were inserted around the radiator tube prior to fitting the tube to the collector. The weld required a very large amount of heat, which made the collector face concave by several thousandths of an inch. Further evidence of oxidation was noted. In spite of the close proximity of the seal ceramic, part No. 6, to the collector weld, it was found that the ceramic had withstood the exposure to the weld heat without cracking. After this step was completed the assembly was accidentally dropped, and the tube 13 broke at the collector end. The fracture was found to be completely brittle, which was a fact consistent with the evidence of oxidation near the welding areas. Since it was a simple matter to re-machine the collector to insert and weld a new cesium tube, and no other radiator tubes were immediately available to start a new assembly, a repair of the failed assembly was attempted. Before the new cesium reservoir tube was welded, however, the assembly was fired at 1400°C to clean the oxidized material. Figure 2 shows the assembly after welding the new cesium reservoir tube. As can be seen, the 1400°C firing had caused some of the coating to disappear or flake off. Upon leak-checking this assembly, it was found that the collector weld to the radiator tube was cracked and leaked.

At this point it was definitely suspected that the welding chamber must have had air leaks in spite of having passed recent examinations for leaks. A thorough leak-check revealed that the argon-pressure manometer had a large leak which was further traced to a cracked soft-solder point of its sensing bellows. The manometer was repaired, and sample niobium welds were run to check that no further oxidation should occur in the chamber during welding. The check is performed by purging the chamber, performing a weld, and then after letting the chamber stand one hour without further attention, performing a second weld. Both welds were clean and ductile, while previously the second weld had completely oxidized and embrittled the sample.

Because the structure of T/E-1-A had become embrittled at the area of the weld of the collector to the radiator tube it could not be repaired, and consequently the fabrication of T/E-1-A was abandoned.

3. Embrittlement of Coated Radiator Tubes

As the next attempt to fabricate the heat pipe model T/E-1 was about to start, a new batch of radiator tubes was received, coated with chromium oxide by the Linde Co. Because the surface of these tubes appeared contaminated, the tubes were cleaned with abrasive cloth and fired at 1400°C. When attempts were made to weld the sodium fill tube, part No. 12, the resulting point was found to be extremely brittle. Further examination, as shown in Figure 3, indicated that the entire

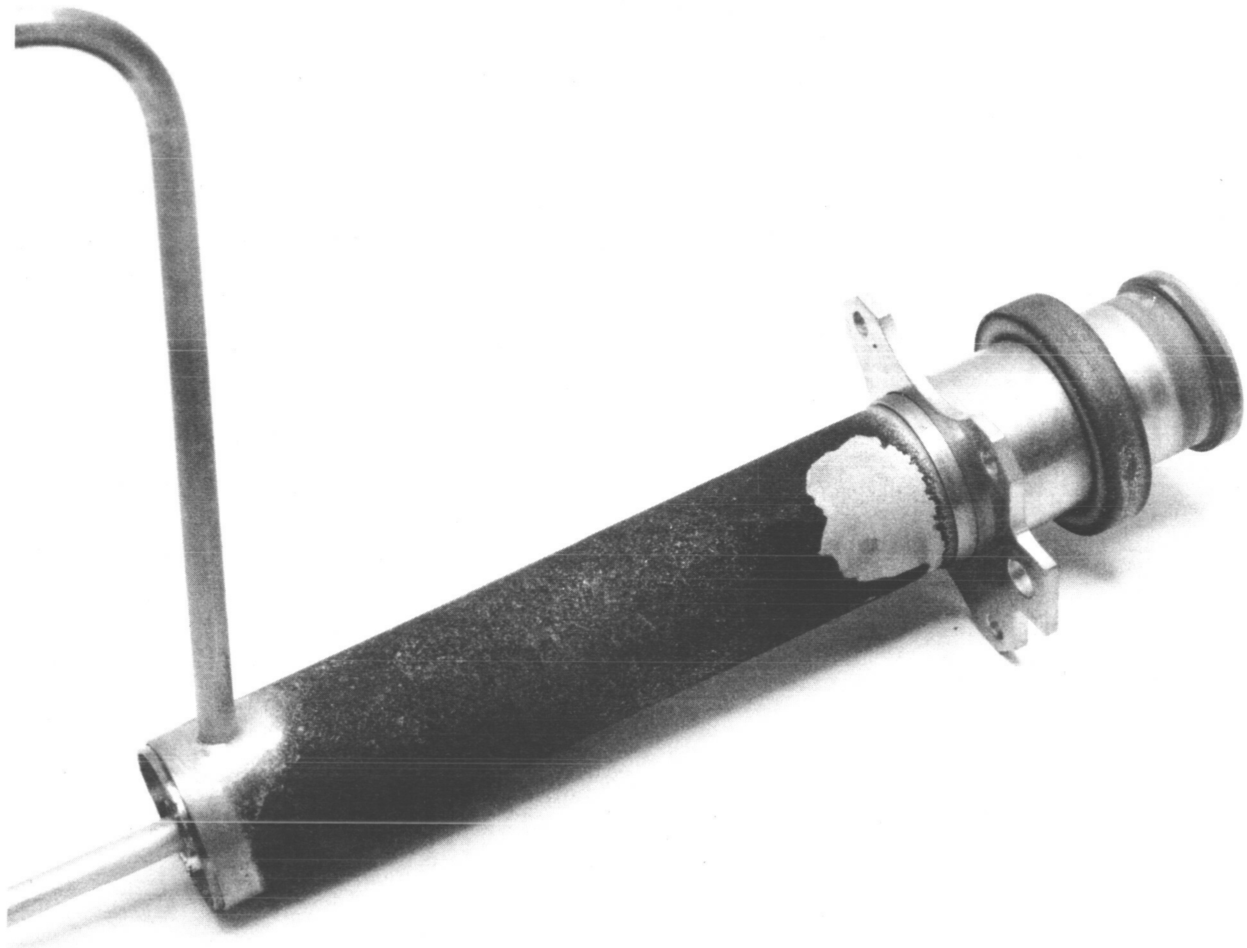


Figure 2

coated surface was brittle, but the uncoated portion of the tube was not. To check whether the embrittlement was common to the coatings of both Linde Co. and New England Hard Facing, the previously welded assembly of T/E-1-A was tested too. As Figure 4 shows, it also was brittle in the area of the coating.

Consequently, a meeting with a representative of the Linde Co. was held to discuss the details of the coating procedure and determine the cause of embrittlement. The representative took note of the facts, and two days later he submitted a tube of the original batch which had been returned to him in order to point out the problem of contamination during coating. This tube was not embrittled. It then became immediately obvious that the embrittlement must have resulted from the vacuum firing at 1400°C that had been used to clean the impurities noticed after coating. This tube sample was then heated for 15-minute intervals to 925°C, 1010°C, 1200°C and 1425°C, and it was found that after the first three firings it was ductile, but after the fourth it was totally embrittled over the coating area. Therefore, the chromium oxide coating material reacts with niobium at some temperature in the range from 1200°C to 1425°C to form a brittle compound.

In order to avoid a need to fire the heat pipe radiator tubes at high temperature to remove residual impurities, an improved fixture was designed and fabricated to carefully shield the portions of the heat pipe that should not be coated during the coating process. This fixture is shown in Figure 5 with a heat pipe radiator tube in position after coating. Figure 6 shows the coated tube as it appears after removal. With the use of such fixtures it is possible to avoid the need for firing the tubes after coating, and the embrittlement problem is thus avoided too.

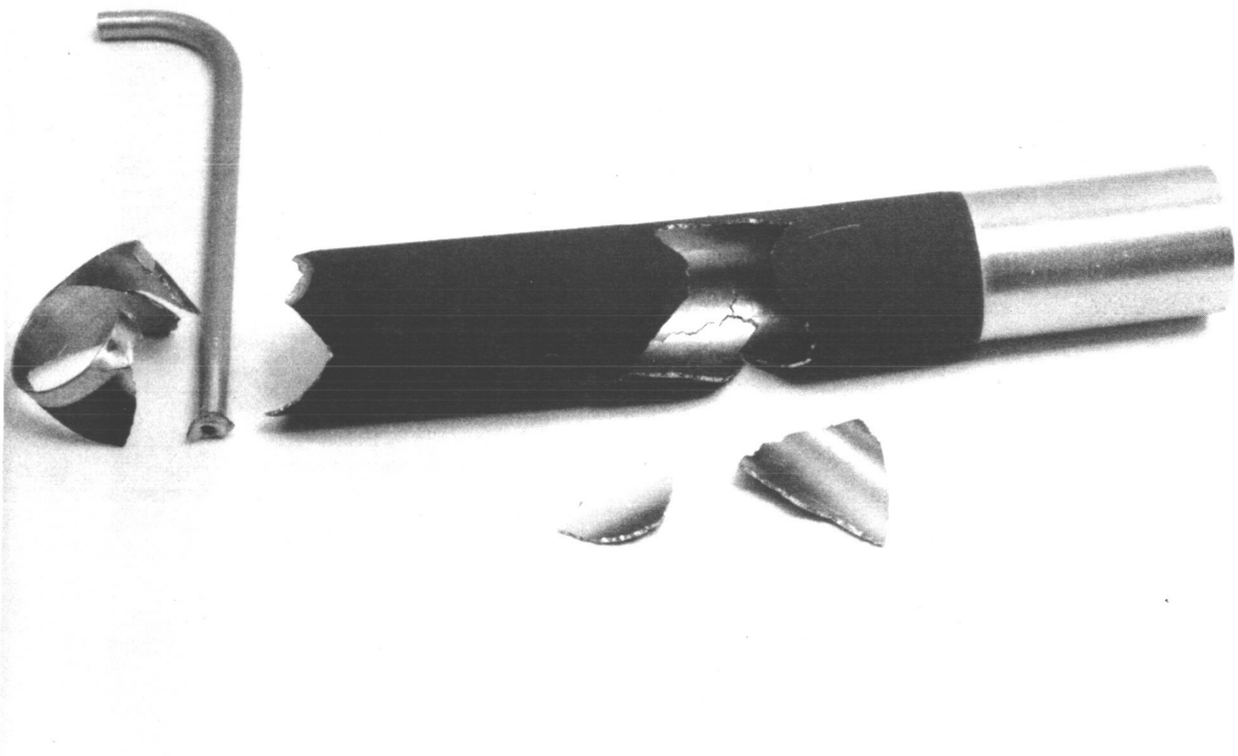


Figure 3

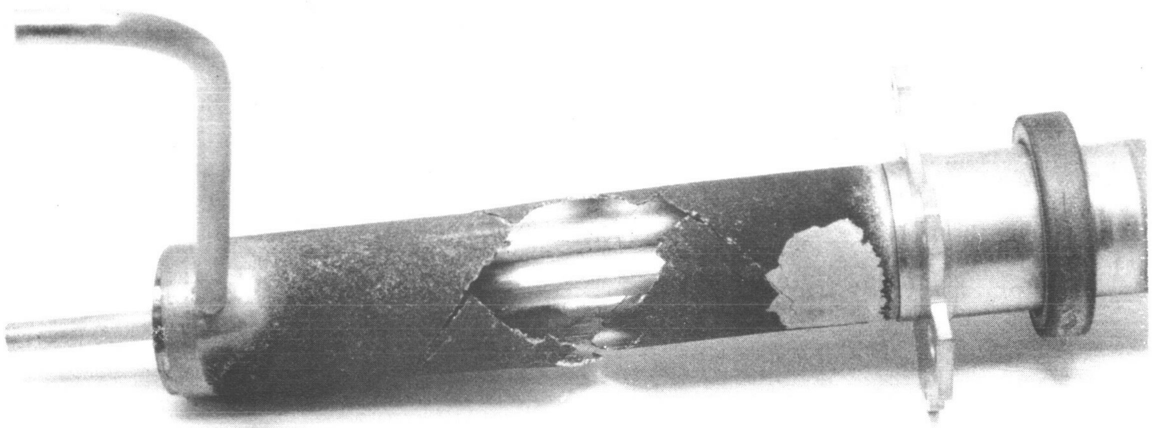


Figure 4

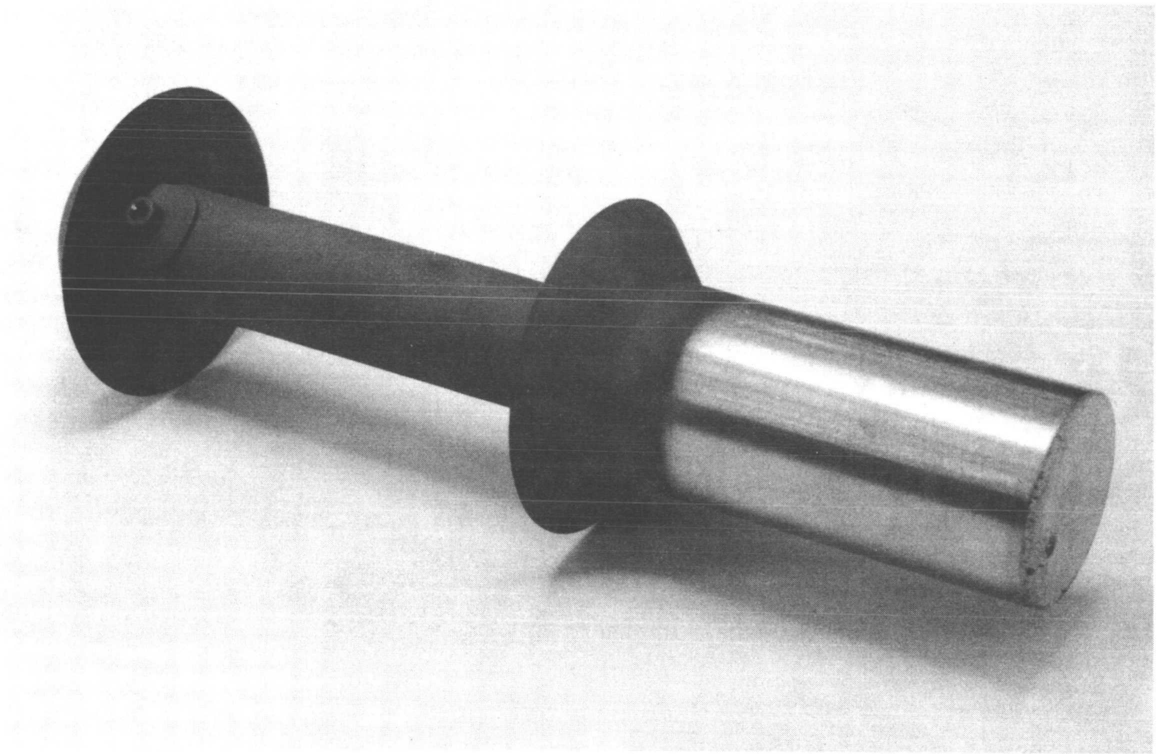


Figure 5

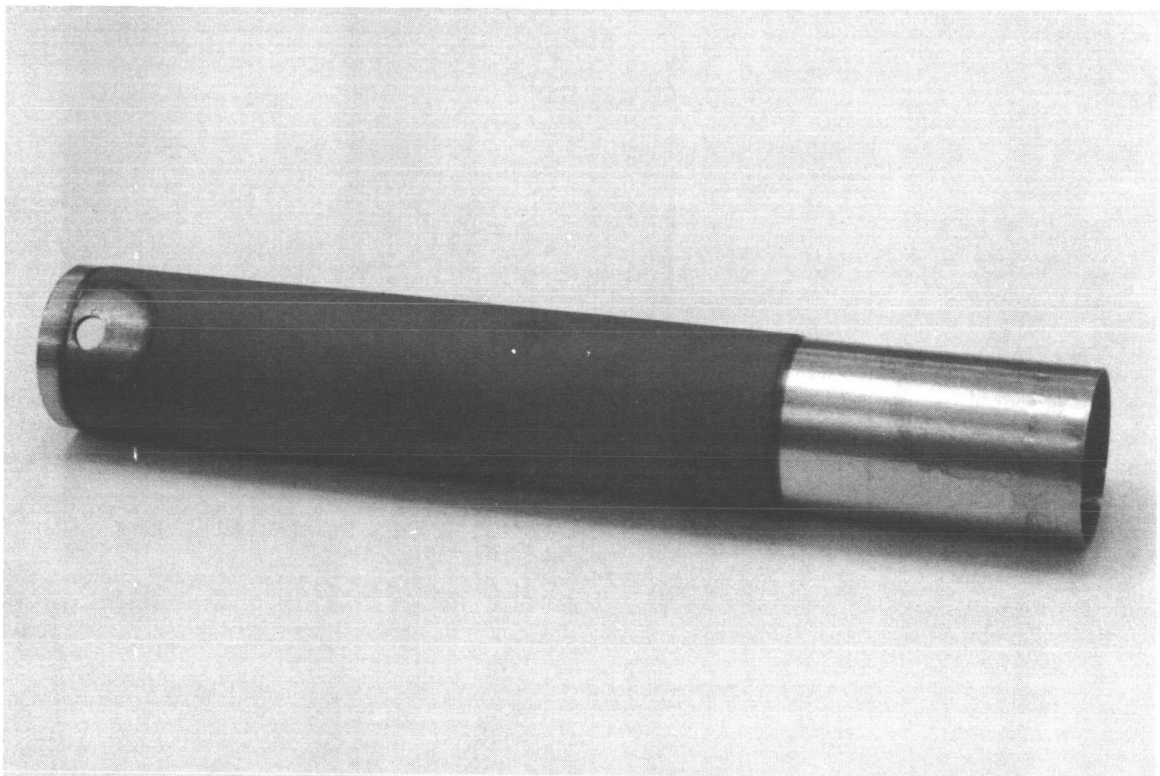


Figure 6

4. Fabrication of T/E-1-B

Since the longest-lead-time part for the fabrication of the heat pipe is the coated heat pipe radiator, and since no un-embrittled ones were immediately available, it was decided, with the approval of the JPL Technical Representative, to omit the coating step in order to save time in the fabrication of T/E-1-B. Also, it was found that the cesium tube, part No. 13, could be joined to the collector face, part No. 8, by means of a palladium braze much easier than it could be arc-welded. Except for these changes, then, the new fabrication attempt was in accordance with the design of Figure 1.

The assembly sequence was as follows: First the heat-pipe inner tube, part No. 14, was welded to the cesium tubulation, part No. 13, at the point corresponding to the vicinity of the collector. Next this assembly was palladium-brazed to the collector face, part No. 8. A sodium fill tube, part No. 12, was arc-welded to the outer heat pipe wall, part No. 9, and this assembly was then set up for welding to the collector face, part No. 8, after insertion of the seal sleeve and support plate, parts Nos. 10 and 11. Upon attempting to weld the collector face to the outer heat pipe tube, part No. 9, the variation in position of the arc from the arc welder tip was sufficient to cause an accidental blow-hole through the wall of the heat pipe close to the location of the weld bead. This accident was remedied by the insertion of a fragment of niobium and localized melting to seal the hole. After this was successfully completed the heat pipe assembly proceeded with the insertion of the capillary mesh screen of the outside wall of the heat pipe and its retaining elements, parts Nos. 16 and 17. One wrap of inner tube mesh was added, and the rear end seal plate, part No. 21, was positioned for final welding, after appropriate insertion of the end mesh elements, part No. 20.

During the welding of the end plate, it was noticed that the weld bead did not behave in the characteristic manner of niobium weld beads. While the final outer weld on part No. 21 was being performed, the welding arc suddenly flashed and pierced a hole through the entire thickness of part No. 21. It was immediately suspected that the capillarry mesh, made of stainless steel, was in sufficient proximity to the weld area to have melted and run into the weld bead, thereby contaminating it with materials that would both embrittle the bead and make the welding arc erratic. To verify this, the end of the heat pipe was opened, and it is shown in Figure 7. Although this may not be readily apparent in the photograph, melting of the capillary mesh was observed both at the inside and outside tubes of the heat pipe. At that point it was decided that the structure could not be salvaged, and the assembly of T/E-1-B was abandoned.

5. Fabrication of T/E-1-C

The assembly of this third heat pipe model was carried out in exactly the same manner as that of the second model. The radiator coating step was omitted, and the same welding difficulties were encountered when an attempt was made to weld the outer heat pipe tube, part No. 9, to the collector face. The welding arc jumped twice on the heat pipe tube, causing blow holes which had to be filled with fragments of niobium locally. In view of this experience, it was decided that in future heat pipe prototypes this weld would be performed by electron-beam welding, where it is possible to control the position of the welding bead with much greater accuracy. In order to avoid the same type of

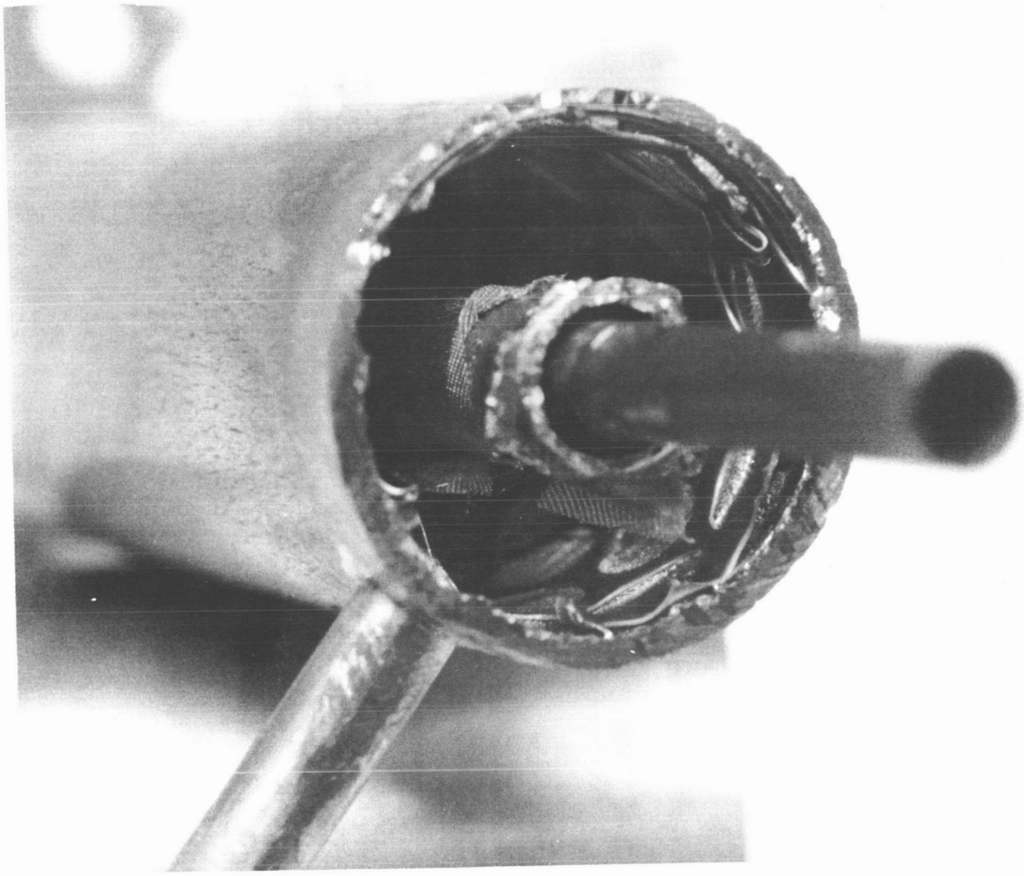


Figure 7

capillary mesh melting which had occurred with T/E-1-B, the capillary mesh was cut short from the end of the tube so that the point of closest proximity would be half an inch away from the welding bead locations. It was then possible to weld the end cap, part No. 21, in place without any difficulty. Figure 8 shows the appearance of the welds of the end cap, and Figure 9 shows the completed heat pipe model, where the repair to the joint at the collector face is apparent.

6. Sodium Charge of T/E-1-C

The heat pipe T/E-1-C was connected to a copper manifold, containing a sodium capsule, by fuse-brazing with electron bombardment the connecting copper tube shown in Figure 1 to the niobium fill tube, part No. 12. The assembly was then connected to a Vac-Ion outgassing stand, heaters were mounted on the heat pipe, the connecting tube and the region of the sodium capsule. The heat pipe was heated under vacuum to 550°C, the connecting tube to 500°C, and the sodium capsule area to 300°C while pumping the internal volume of the heat pipe with a Vac-Ion pump. After 9 days of continuous pumping, the sodium capsule was broken, exhausted for one additional hour, and pinched off at a vacuum of 4×10^{-8} torr. Heat was then applied to the sodium capsule region with the intent of transferring the sodium into the heat pipe by distillation. It was estimated that this would require 48 hours at 430°C. At the end of 24 hours, however, the bell jar of the vacuum system used for distillation was found coated with sodium. A leak in the sodium reservoir was located at a BT braze of copper pieces.

The sodium capsule manifold was then severed from the heat pipe, and the heat pipe was placed in vacuum at 700°C for 24 hours to remove the sodium distilled into it. A new manifold was attached, and the

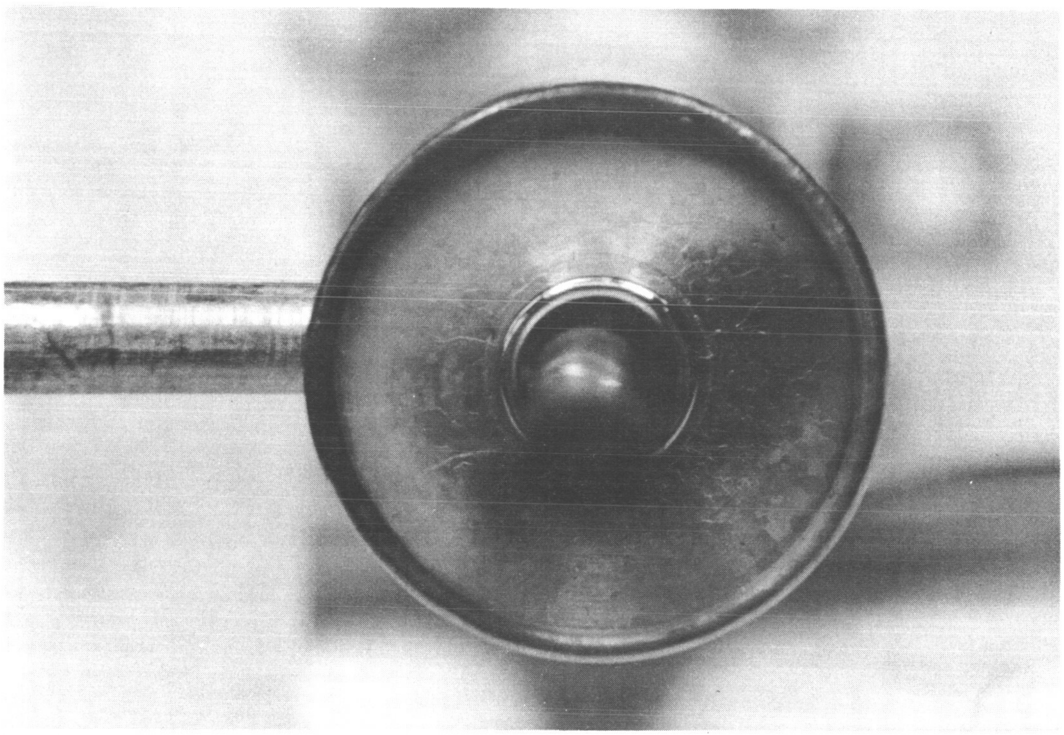


Figure 8

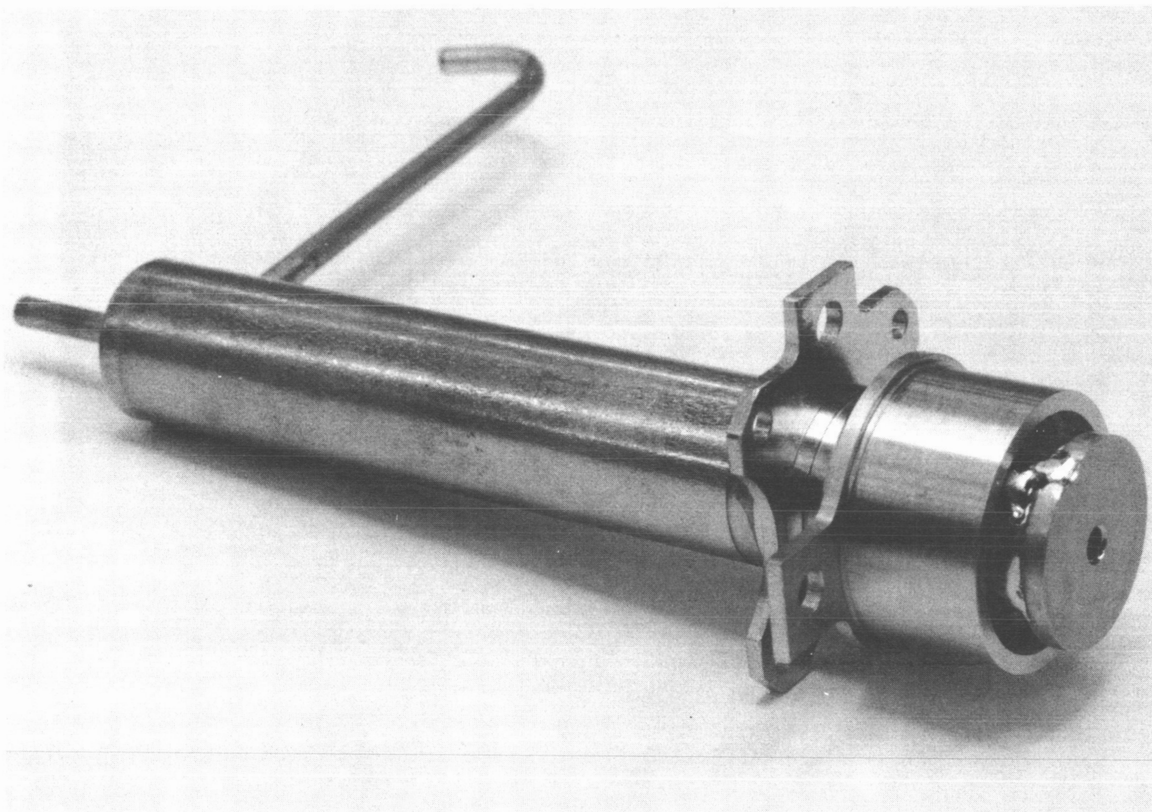


Figure 9

heat pipe was again outgassed to a vacuum of $4x10^{-8}$ torr. The outgassing time was 6 days. The same distillation procedure was attempted, but in one hour the copper pinch-off of the manifold developed a sodium vapor leak.

The distillation procedure was then reviewed, and it was decided to abandon it in favor of direct gravity transfer of the liquefied sodium. The heat pipe with the leaky manifold was quickly inverted and placed back under vacuum in such a manner that the sodium could be taken to the melting point and caused to flow into the heat pipe. Once this was done, the copper manifold was pinched off, and the heat pipe was set up for the final sealing operation, which involves pinching off the niobium fill tube, part No. 12, by electron bombardment.

The electron-bombardment pinch-off operation was carried out by placing a one-turn 0.030-in.-dia. tantalum filament around the fill tube. This filament turn was 0.35 in. in diameter, and included a turn overlap of 0.20 in. so as to avoid the effect of local bombardment current, which is caused by lower filament temperature at the connection legs. When the fill tube was bombarded, the bombardment opposite the filament overlap area was found to be excessive; the fill tube melted locally at that point and developed a hole. Since a substantial amount of sodium vapor evaporated through this hole, the bombardment filament would no longer be maintained at a high potential difference with respect to the fill tube without violent arcing.

The vacuum system was opened to air in order to determine that this was what had happened. Since air leaked into the heat pipe in large amounts then, it was determined best to use the heat pipe structure to repeat the electron-bombardment pinch-off operation with a filament that did not have a turn overlap. This second pinch-off was successful, and is shown in Figure 10. The failed attempt is also evident in this figure. The complete structure of T/E-1-C is shown in Figure 11.

7. Fabrication of T/E-1-D

The heat pipe model T/E-1-D is being fabricated according to the standard design of Figure 1 except that, as a result of the experience gained in the previous fabrication attempts, it will incorporate the palladium braze of the cesium tube to the collector, an electron-beam weld of the radiator tube to the collector, and a shortened capillary mesh such as used in T/E-1-C. The model will also incorporate a coated radiator tube. It is intended to fill the heat pipe by gravity flow under vacuum, and then to operate it while pumping on it. Final pinch-off will probably be performed by electron bombardment with a filament free of turn overlap. As of the end of this reporting period, the model had a leak at the electron-beam weld between the radiator tube and the collector, and it was to be repaired by re-welding.

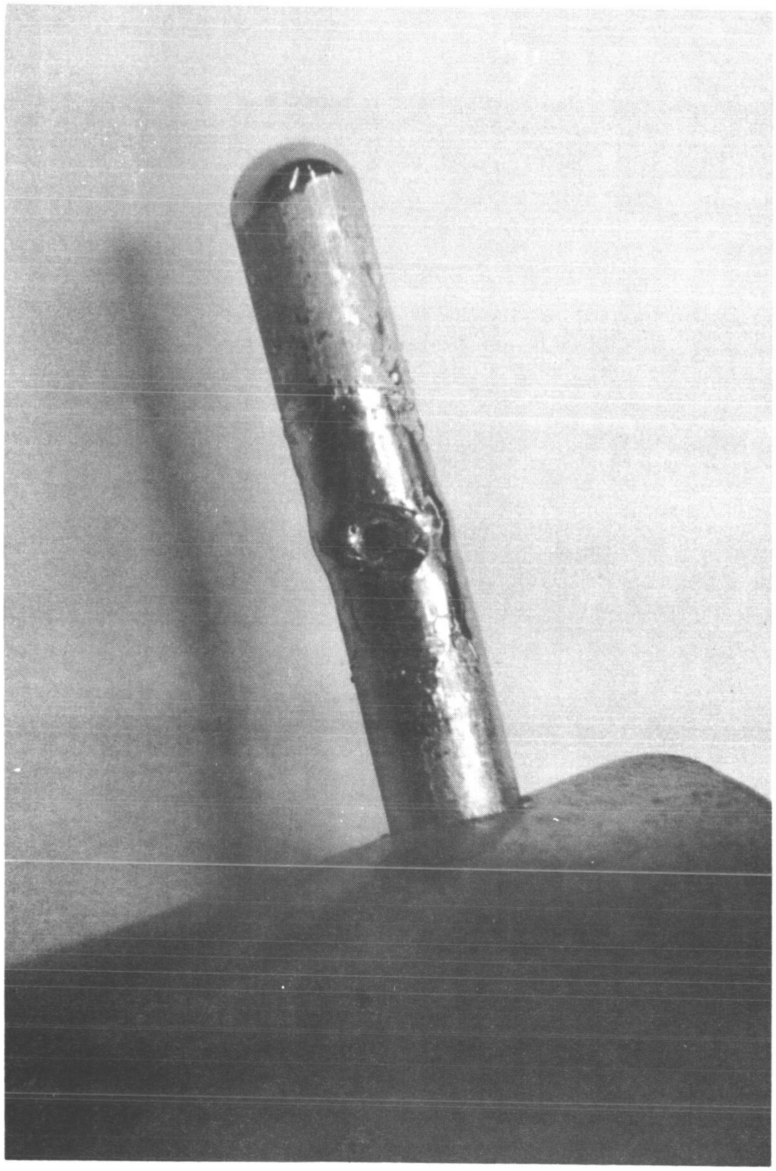


Figure 10

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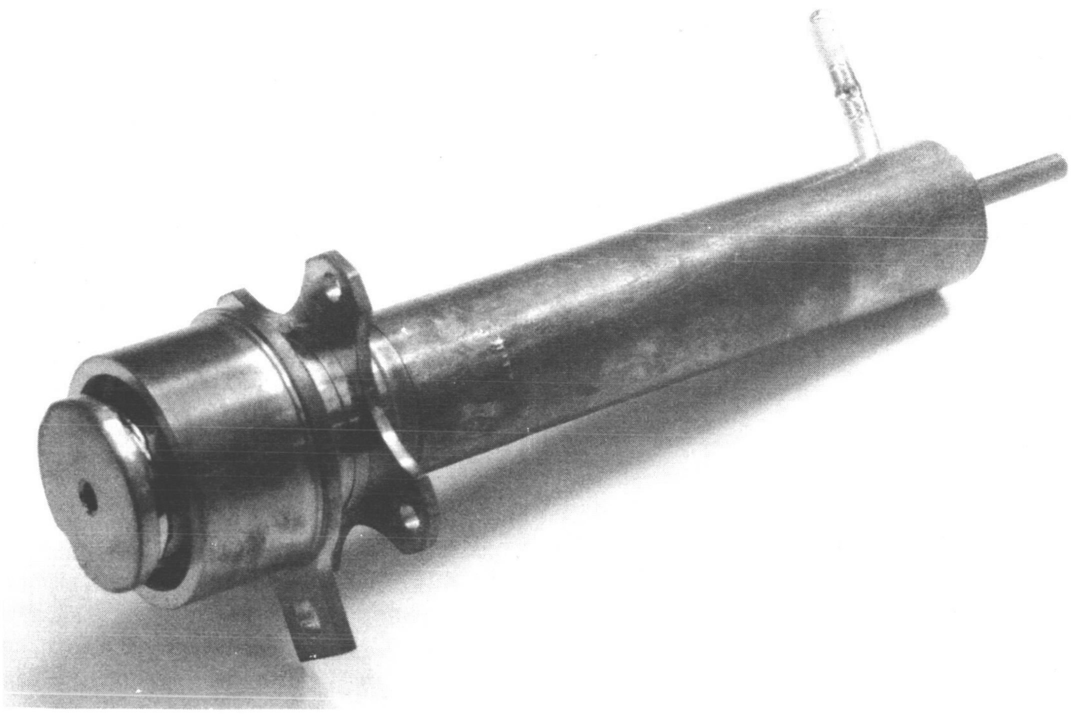

Figure 11